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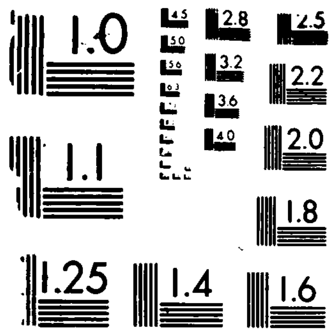

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MEMORANDUM REPORT BRL-MR-3573

AUTOMATIC PLOTTING ROUTINES FOR ESTIMATING STATIC AERODYNAMIC PROPERTIES OF FLARED PROJECTILES FOR 2<M<5

WILLIAM F. DONOVAN

MARCH 1987

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US ARMY BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

REPORT DOCUMENTATION PAGE

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A predictive program for the estimation of static aerodynamic coefficients for flared projectiles at 2<M<5 is presented in HP9845 computer context. The technique is demonstrated by application to a typical projectile for which range data is available for completion.

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I. INTRODUCTION

The aerodynamic performance of flared projectiles has not been investigated in detail - either by the wind tunnel techniques, which usually focus on the effects of perturbations of the flare geometry; or on the free flight ranges, which normally employ the flare for its strong stabilizing influence in order to survey some other performance parameter. For a given projectile, the wind tunnel experiments can efficiently determine axial force, normal force and spin deceleration characteristics and the influence of the Reynolds number on these coefficients. However, the dynamic coefficients, C_{M_p} and $C_{M_q} + C_{M_\alpha}$, are not easily established and the axial force coefficient is clearly not equivalent to the drag coefficient which is required for application design. Free flight ranges are most suitable for measurements of the drag and the dynamic coefficients and, ultimately, the dispersion and accuracy.

The few flare control data available verify that the high drag associated with the flare makes such a projectile unattractive for anything but very short range applications, although a recent publication in the form of a careful computational study describes a very novel flare concept which will require evaluation by experimental methods.

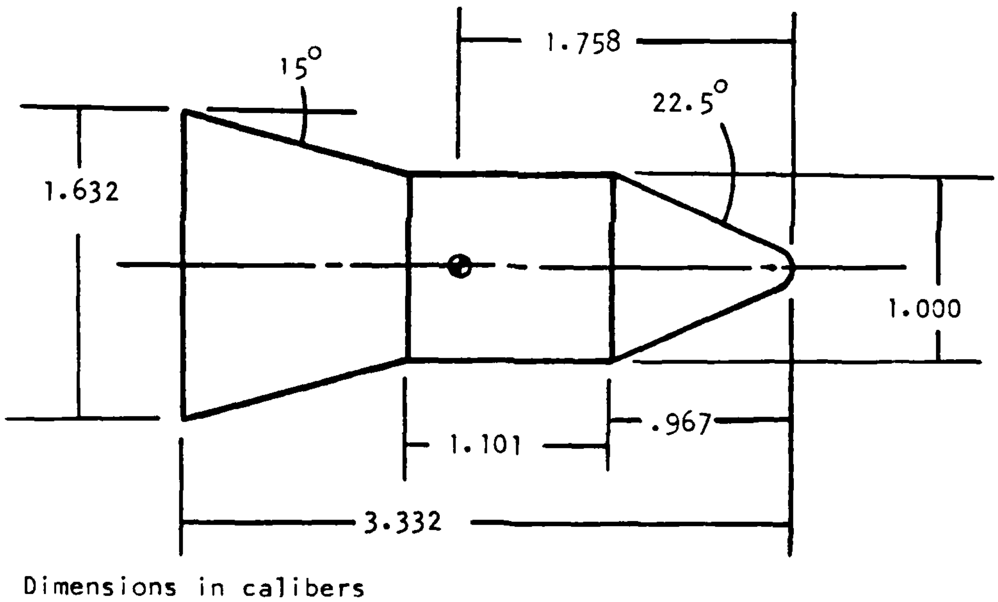
This present report is intended to be used in the formulation of quick estimates of the static aerodynamic characteristics of the conventional flared projectile. The data is based primarily on References 2 and 5 and the exposition follows that of the corresponding finned projectile presentation. The drag, static moment and normal force coefficients are determined from the simplified geometry of the projectile and the bounding aerodynamic conditions, i.e., sea level, flat fire, $2<M<5$, and small yaw. The computer program is written in the Hewlett-Packard Basic language and is easily convertible to other Basic-language microcomputers.

II. PROCEDURE AND RESULTS

The empirically-developed expressions for the aerodynamic contributions of the components are based on those of the corresponding elements for the similar finned projectile - following the form of Reference 5. Modifications are introduced as indicated by the test data of Reference 2. Caliber notation, where a representative linear dimension indicates a reference length and the mass/force dimension is converted to a specific gravity equivalent, is used in the physical description and in the interior of the program operation.

Figure 1 is a sketch and Figure 2 is a set of shadowgraphs of a flared projectile. Tables 1, 2 and 3 define the equations used to describe the aerodynamic parameters. The initialization instructions are presented in Appendix A and the full program listings follow. Figures 3.a through 3.g present a projectile outline, input tabulation, a table of the static aerodynamic coefficients and graphs of the normal force slope, drag, static moment slope, lift force slope, accuracy factor and velocity decrement. The range is $2<M<5$.

This is an interactive program, i.e., the operator responds to specific requests from the computer, which permits selective options of the output.



Wt.	3.11 lb.	(4.11 cal^3)
I_y	11.94 lb.-in^2	(2.08 cal^5)
d	2.757 in.	(1.0 cal)

Figure 1. Outline Sketch of Flared Projectile (Reference 2)

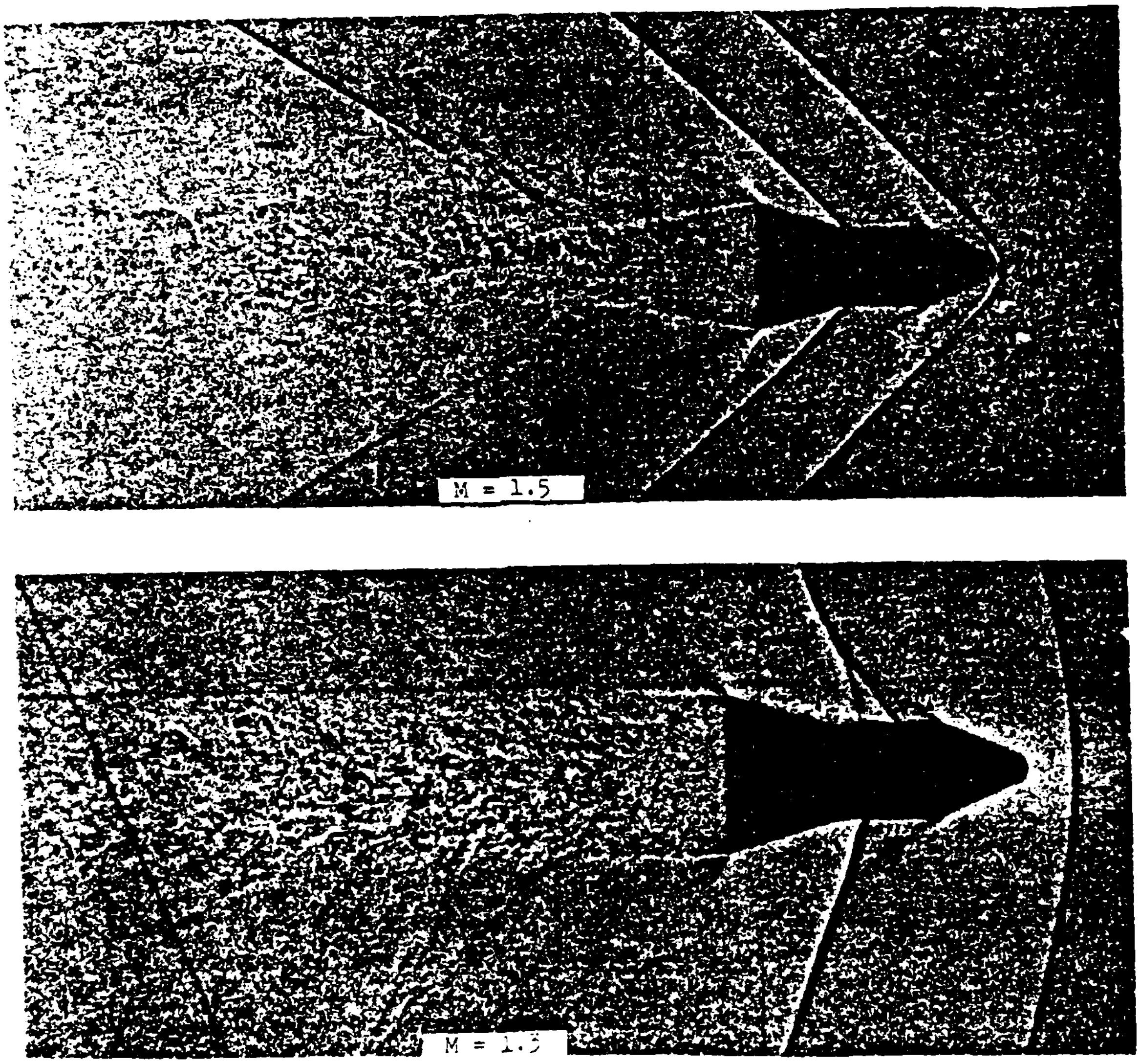


Figure 2. Shadowgraphs of Minuteman Missile Model in Flight (Reference 2)

TABLE 1. DRAG COEFFICIENT

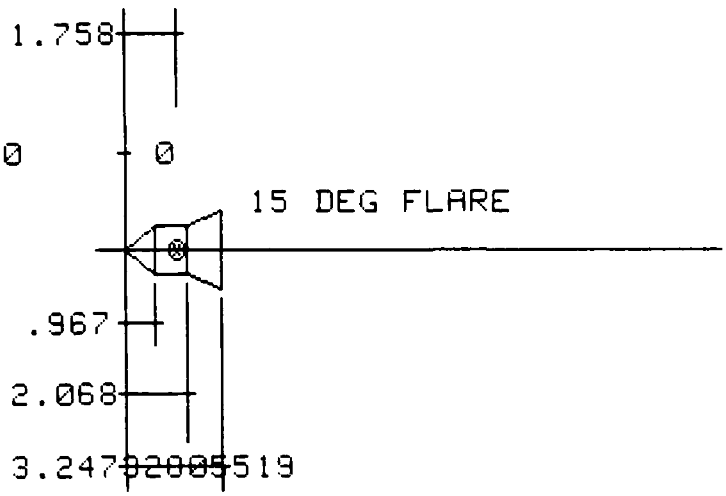
	DRAG COEFFICIENT
$\text{Wave}_{\text{Nose}}$	$C_{DWN} = .7M^{-.28}\ \ell_n^{\ -1.73}$
Base	$C_{DB} = e^{.6\theta}(-0.048\ M + .265)\ d_b^{\ 2}$
Viscous	$C_{DV} = 0.000173\ (28.75 - 4.166\ M)\ \dfrac{A_{\text{wetted surface}}}{A_{ref}}$
$\text{Wave}_{\text{Flared}}$	$C_{DWF} = \dfrac{3\theta}{M}\ (0.75 - \dfrac{0.6}{d_b})$
Grooves	$C_{DGR} = .00025\ M^{3.9}\ \Delta\ \ell_{GR}\ (C_{DWN} + C_{DV} + C_{DWF})$
Total	$C_{DT} = C_{DWN} + C_{DB} + C_{DWF} + C_{DGR}$

TABLE 2. NORMAL FORCE AND STATIC MOMENT SLOPE COEFFICIENT

Normal Force and Static Moment Coefficients			
Nose Datum	Body	Normal Force Coefficient	$C_{N\alpha B} = \left(1.9 + 1.3 \frac{\beta}{\ell_n} + .0149 \frac{\ell_a}{\beta}\right)(\beta^{-.7})(.6103 + .036M)$
		Center of Pressure of Normal Force	$x_{c.p.B} = \left(.89 + .75 \frac{B}{\ell_n} + .5 \frac{\ell_a}{\beta}\right) M^{2.5} \beta^{1.98}$
		Static Moment Coefficient	$C_{M\alpha B} = (x_{c.p.B})(C_{N\alpha B})$
	Flare	Normal Force Coefficient	$C_{N\alpha F} = \left(2.67 - \frac{.67}{d_b}\right)(\cos\theta)(M/\beta)$
		Center of Pressure of Normal Force	$x_{c.p.F} = \ell_n + \ell_a + .1\,(d_b - 1)/\tan\theta$
		Static Moment Coefficient	$C_{m\alpha F} = (x_{c.p.F})(C_{N\alpha F})$
	Assembly	Normal Force Coefficient	$C_{N\alpha} = C_{N\alpha B} + C_{N\alpha F}$
		Static Moment Coefficient	$C_{M\alpha} = C_{M\alpha B} + C_{M\alpha F}$
		Center of Pressure of Normal Force	$x_{c.p.} = C_{M\alpha}/C_{N\alpha}$
Gravity Datum	Assembly	Normal Force Coefficient	$C_{N\alpha} = C_{N\alpha}$
		Center of Pressure of Normal Force	$x_{c.p.} = x_{c.p.}$
		Static Margin	$\Delta x = x_{c.p.} - x_{c.g.}$
		Static Moment	$C_{M\alpha} = (x_{c.p.} - x_{c.g.})(C_{N\alpha})$

TABLE 3. RETARDATION AND ACCURACY FACTOR

Retardation	
Mach Number along Trajectory	$M_1 = \frac{b}{R\,e^{Qs} - c}$
Average Velocity Decrement	$\Delta v = \frac{M_0 - M_1}{s} (v)_{sonic}$
Accuracy Factor	
Accuracy Factor	$J_\zeta = \frac{C_{L\alpha}}{C_{M\alpha}} \frac{I_y}{md^2}$



WT = 4.11 WCAL3

IX = 0 ICAL5

IY = 2.08 ICAL5

DIA= 2.757 IN/CAL

ALL VALUES ARE IN CALIBERS UNLESS OTHERWISE NOTED

CONICAL NOSE LENGTH: .967
CYLINDRICAL BODY LENGTH: 1.101
GROOVE LOCATION/NOSE: 0
GROOVE LENGTH: 0
MAX FLARE DIAMETER: 1.632
FLARE ANGLE: 15
0.00
CENTER OF GRAVITY: 1.758
MACH NUMBER AT MUZZLE: 3
MAXIMUM RANGE (METERS): 1000
PROJECTILE WEIGHT (CAL3): 4.11
AXIAL MOMENT OF INERTIA (CAL5): 0
TRANSVERSE MOMENT OF INERTIA (CAL5): 2.08
1.0 CALIBER REFERENCE DIAMETER (IN.): 2.757

Figure 3a. Computer-Generated Output: Projectile Outline and Input Parameters

STATIC AERODYNAMIC COEFFICIENTS FOR
LONG ROD FLARED PROJECTILES

MACH NUMBER

	2.0	2.5	3.0	3.5	4.0	4.5	5.0
CNAB	1.976	1.911	1.888	1.883	1.887	1.898	1.911
XCPB	1.331	1.507	1.631	1.730	1.817	1.894	1.966
CMAB	2.629	2.880	3.079	3.258	3.428	3.594	3.757
CNAF	2.520	2.381	2.315	2.277	2.254	2.238	2.227
CNAT	4.496	4.293	4.203	4.160	4.141	4.136	4.139
CMAT	8.435	8.366	8.412	8.505	8.621	8.751	8.889
CG-CP	-.118	-.191	-.244	-.286	-.324	-.358	-.390
CMAT,CG	-.532	-.819	-1.023	-1.191	-1.341	-1.480	-1.613
CDWN	.611	.574	.545	.522	.503	.487	.473
CDB	.527	.452	.377	.302	.227	.153	.078
CDV	.046	.041	.037	.032	.027	.022	.018
CDGR	0.000	0.000	0.000	0.000	0.000	0.000	0.000
CDWF	.150	.120	.100	.086	.075	.067	.060
CDT	1.334	1.187	1.059	.942	.833	.729	.628
CLA	3.162	3.105	3.143	3.218	3.308	3.407	3.510
J ZETA	-3.009	-1.918	-1.554	-1.367	-1.249	-1.165	-1.102

Figure 3b. Computer-Generated Output: Table of Aerodynamic Coefficients

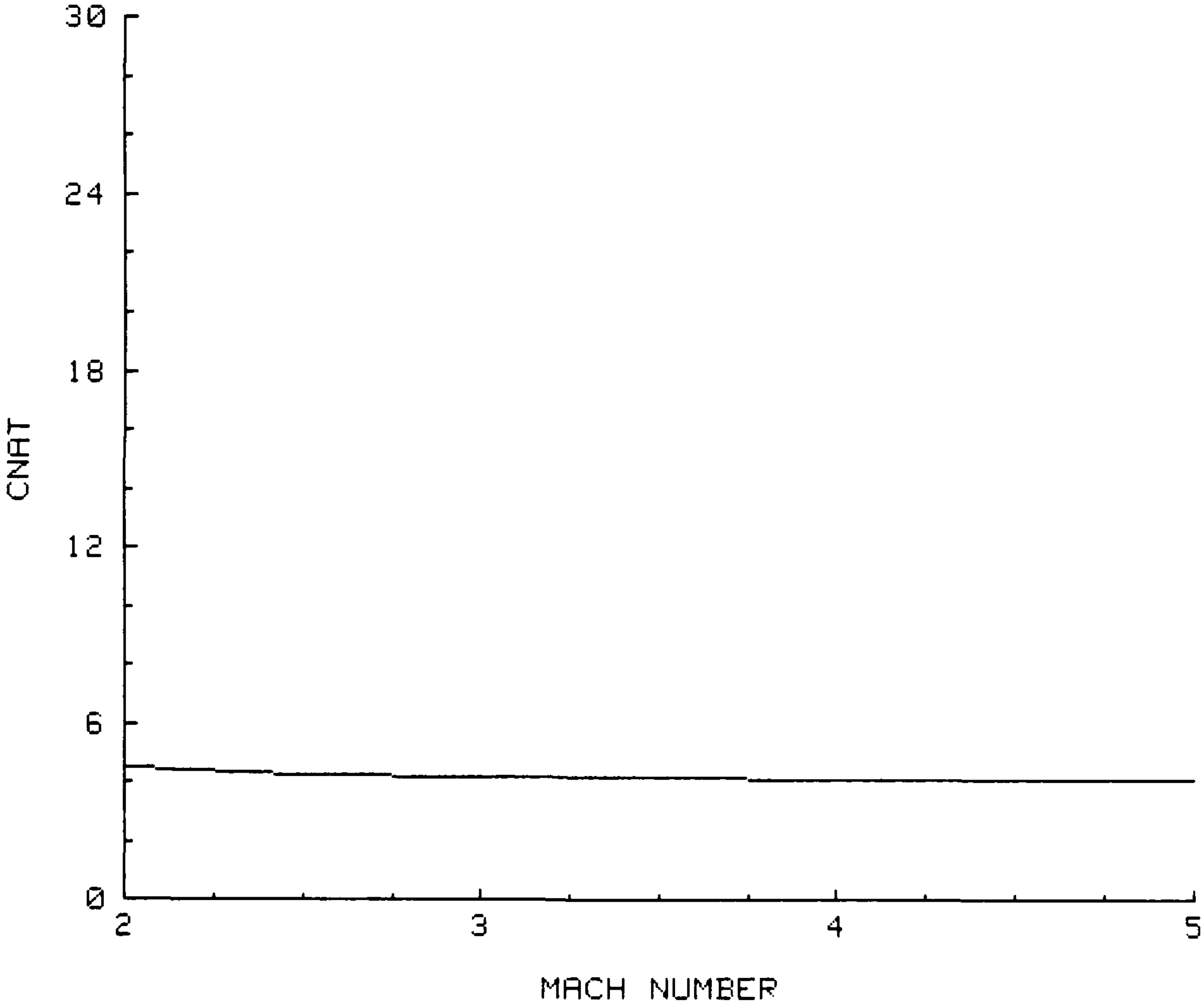


Figure 3c. Computer-Generated Output: Normal Force Slope Coefficient

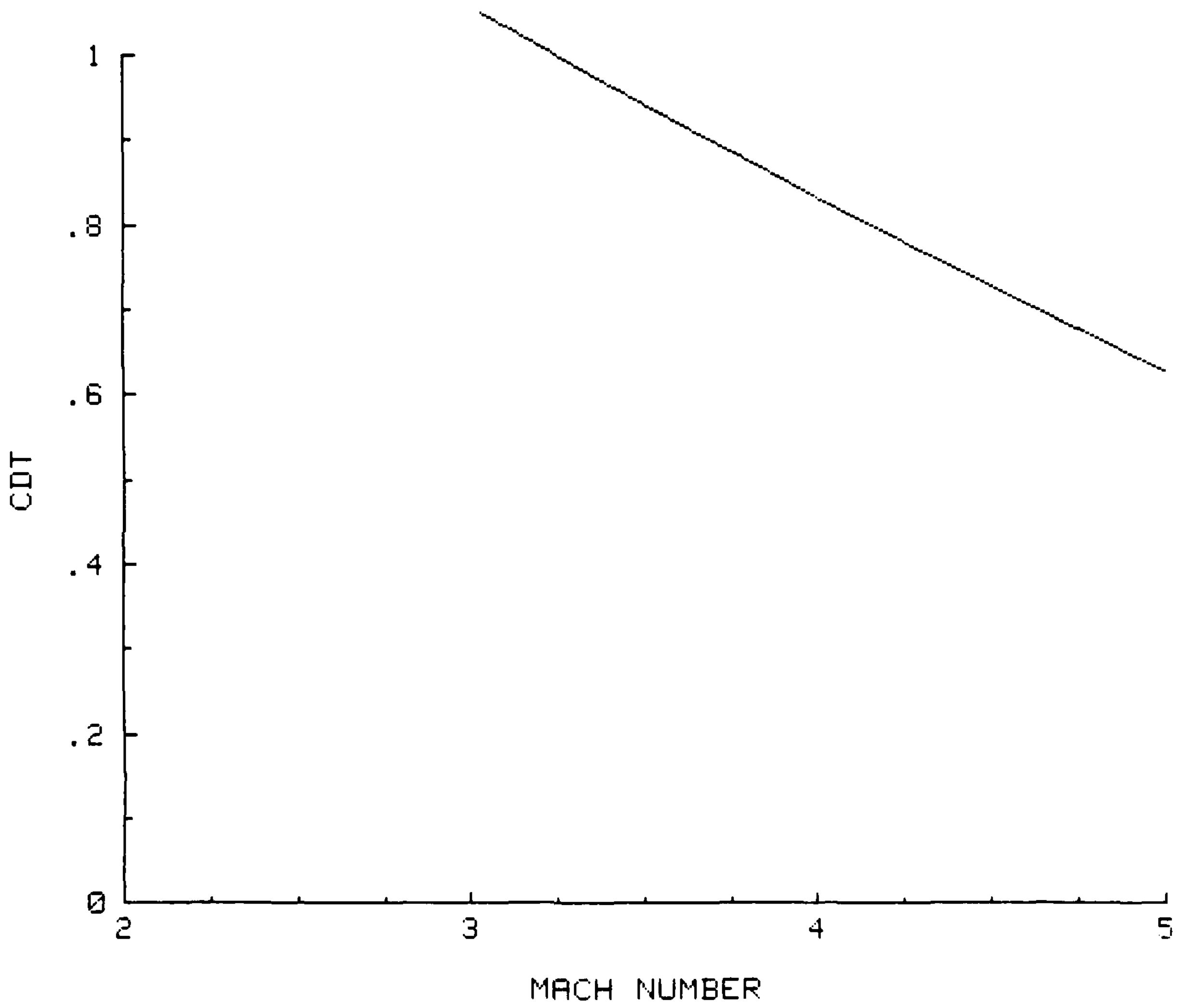


Figure 3d. Computer-Generated Output: Zero-Yaw Drag Coefficient

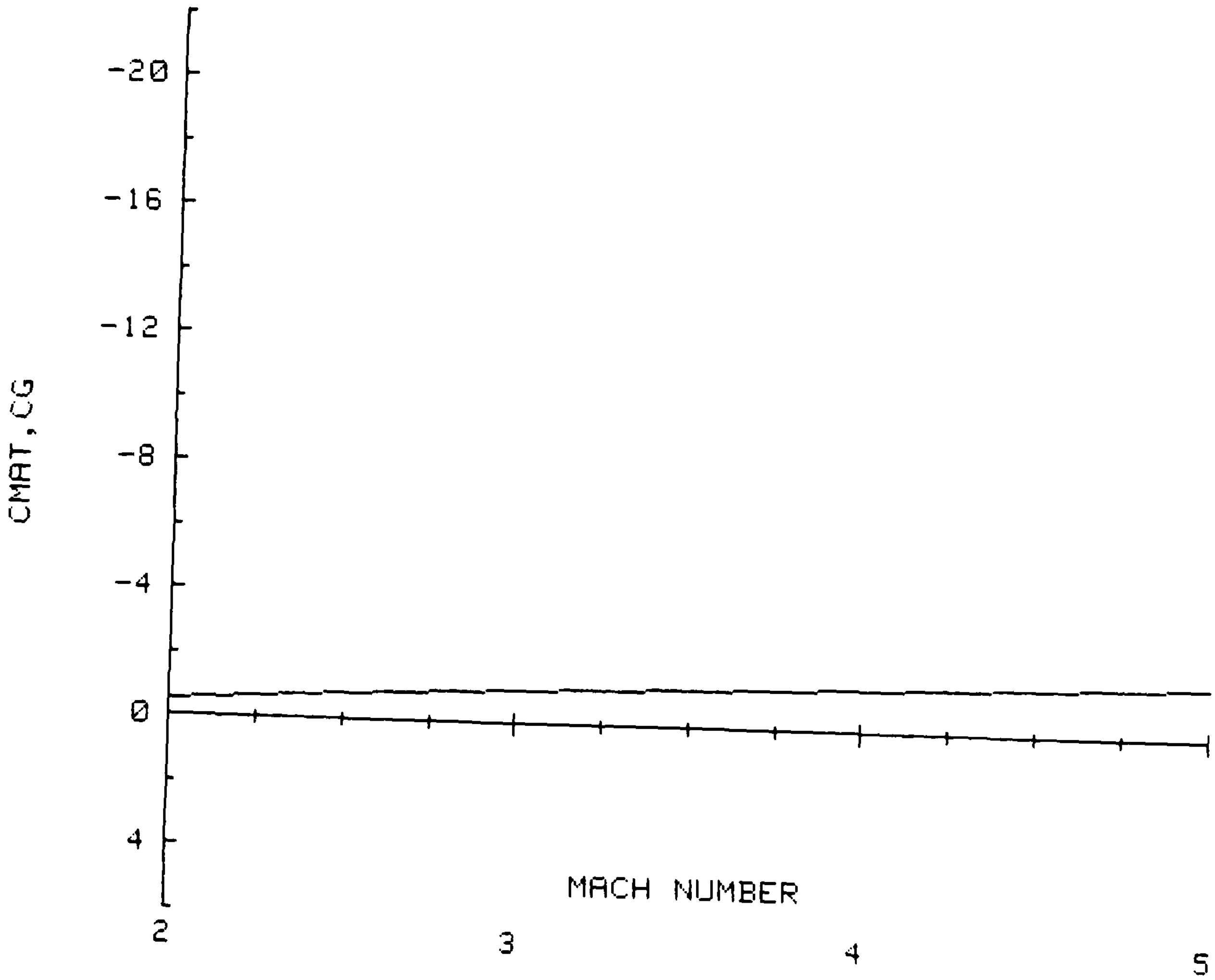
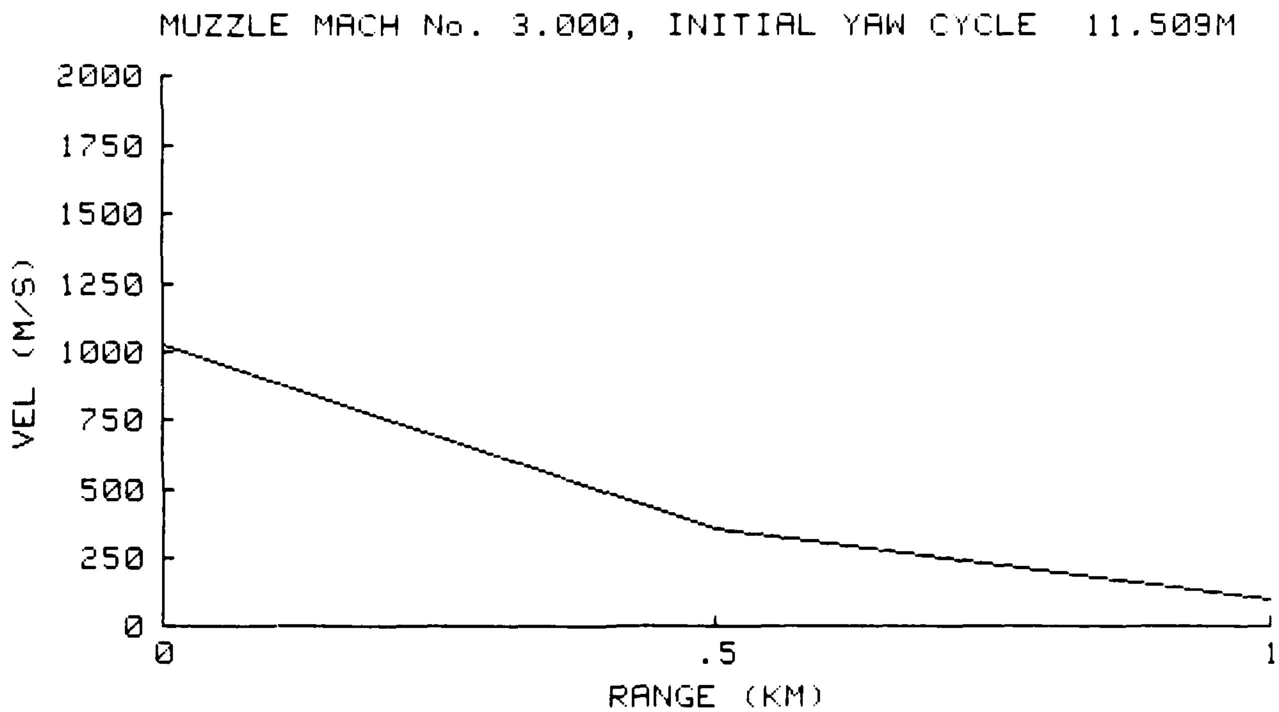


Figure 3e. Computer-Generated Output: Static Moment Slope Coefficient



RANGE 0 M, RETARDATION1340.284 M/S/KM
RANGE 500 M, RETARDATION1340.284 M/S/KM
RANGE 1000 M, RETARDATION 927.116 M/S/KM

Figure 3f. Computer-Generated Output: Trajectory Parameters

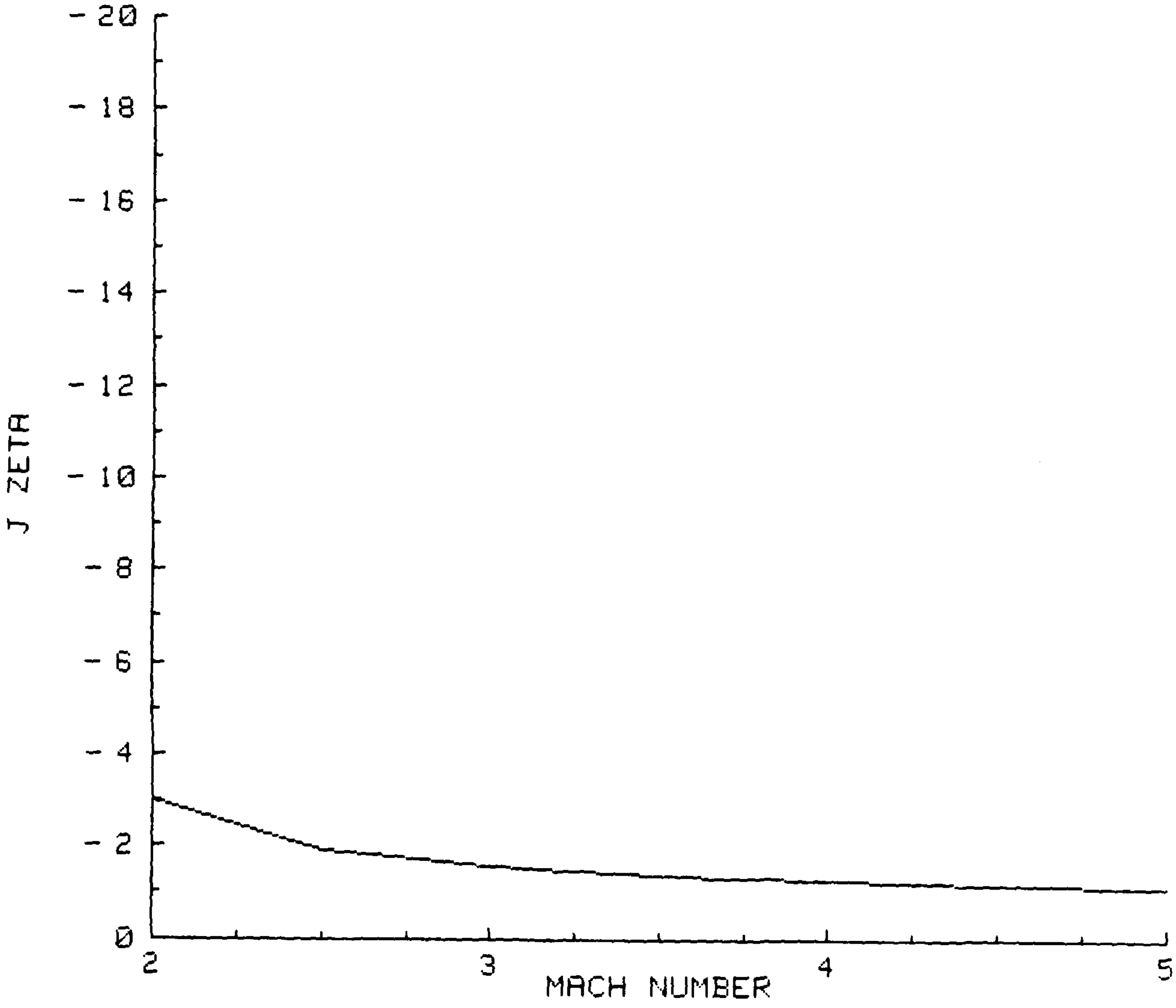


Figure 3g. Computer-Generated Output: Accuracy Factor

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4. M.J. Nusca, "Numerical Investigation of the Aerodynamics of a Flared Afterbody for Axisymmetric Projectiles at Supersonic Speeds," ARBRL-TR-02535, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, 21005, December 1983 (AD #136862).

5. AMCP 706-280, "Design of Aerodynamically Stabilized Free Rockets," 1968.

6. W.F. Donovan, M.J. Nusca and S.A. Wood, "Automatic Plotting Routines for Estimating Static Aerodynamic Properties of Long Rod Finned Projectiles," BRL Memorandum Report No. ARBRL-MR-03123, August 1981 (AD #104900).

LIST OF SYMBOLS

b	Intercept of C_D vs M characteristic
c	Slope of C_D vs M characteristic
c.g.	Center of gravity of projectile, nose datum
c.p.	Center of pressure of normal force
d	1.0 cal, reference diameter
d_b	Diameter of base of flare
e	Base of Natural log
ℓ_a	Cylindrical body length
ℓ_{gr1}	Groove length from nose (starting groove)
ℓ_{gr2}	Groove length from nose (last groove)
$\Delta\ell_{gr}$	Groove length
ℓ_n	Nose length
m	Mass of projectile
s	Range
v	Velocity of projectile
Δv	Velocity decrement over specified range
$x_{c.p.B}$	Center of pressure of normal force on body
$x_{c.p.F}$	Center of pressure of normal force on flare
A_{ref}	Reference area (.785 cal^2)
A_{wetted}	Surface Area of lateral surface producing viscous flow drag
C_D	$\frac{\text{Drag Force}}{\frac{1}{2}\rho v^2 A_{ref}}$, zero-yaw drag coefficient
C_{DB}	Pressure drag coefficient - base of flare

LIST OF SYMBOLS (continued)

C_{DGR} Drag coefficient due to grooves

C_{DT} Total Drag coefficient

C_{DWN} Wave drag coefficient - body (nose)

C_{DWF} Wave drag coefficient - flare

$C_{L\alpha}$ $\dfrac{\text{Lift Force}}{\frac{1}{2} \rho v^2 A_{ref} \delta}$, aerodynamic lift slope coefficient, $\delta = \sin \alpha_T$

$C_{M\alpha}$ $\dfrac{\text{Static Moment}}{\frac{1}{2} \rho v^2 A_{ref} d\delta}$, aerodynamic moment slope coefficient

$C_{M\alpha B}$ Static moment coefficient - body

$C_{M\alpha F}$ Static moment coefficient - flare

$C_{N\alpha}$ $\dfrac{\text{Normal Force}}{\frac{1}{2} \rho v^2 A_{ref} \delta}$, aerodynamic normal force slope coefficient

$C_{N\alpha B}$ Normal force coefficient - body

$C_{N\alpha F}$ Normal Force coefficient - flare

I_x Axial moment of inertia

I_y Transverse moment of inertia

J_ζ $\dfrac{I_y}{md^2} \dfrac{C_{L\alpha}}{C_{M\alpha}}$, aerodynamic jump factor

LIST OF SYMBOLS (continued)

M	Mach number
M_0	Mach number at muzzle
M_1	Mach number along trajectory
Q	Operational parameter, $\frac{\rho A_{ref} b}{2m}$
R	Operational parameter, $\frac{c M_o + b}{M_o}$
α	Angle of attack, employed here as a subscript
β	$(M^2 - 1)^{1/2}$, operational parameter
δ	Sine of total angle of attack
ζ	Dispersion parameter, employed here as a subscript
θ	Flare half-angle
π	3.1416
ρ	Ambient air density

APPENDIX A

INITIALIZATION INSTRUCTIONS

APPENDIX A

INITIALIZATION INSTRUCTIONS

To use this program, the operator requires only the entry of the geometry and the physical properties of the projectile, the range excursion and the muzzle Mach number. Caliber notation, where a representative linear dimension provides a reference length and the mass/force dimension is converted to a specific gravity equivalent, is employed extensively. The reference diameter may be in inches or in millimeters and the range input in meters.

The program will call for the operator to respond as required.

```
10    OPTION BASE 1    ! PROGRAM FILE "FLARE"
20    DIM Q(20,7),Q1(7),A$(1),R2(20),R3(20),V(20)
30    INTEGER Array_t(0:23835),Array_b(0:23940)
40    PRINT PAGE
50    BEEP
60    PRINT "THIS PROGRAM WILL CALCULATE AND PLOT ESTIMATED"
70    PRINT " STATIC AERODYNAMIC COEFFICIENTS OF LONG ROD"
80    PRINT "FLARED PROJECTILES IN THE MACH RANGE 2-5"
90    PRINT
100 Proj_design:  PRINT
110   Computed=0
150   PRINT "INPUT THE FOLLOWING VALUES IN CALIBERS:"
160   PRINT "  CONICAL NOSE LENGTH: "
170   BEEP
180   INPUT L
181   PRINT "L  ";"CONICAL NOSE LENGTH";L
190   PRINT "  CYLINDRICAL BODY LENGTH: "
200   BEEP
210   INPUT L1
211   PRINT "L1  ";"CYLINDRICAL BODY LENGTH";L1
220   PRINT "  GROOVE LOCATION/NOSE: "
230   BEEP
240   INPUT P1
241   PRINT "P1  ";"GROOVE LOCATION/NOSE";P1
250   PRINT "  GROOVE LENGTH: "
260   BEEP
270   INPUT P2
271   PRINT "P2  ";"GROOVE LENGTH";P2
280   PRINT "  MAX FLARE DIAMETER"
290   BEEP
300   INPUT H3
310   PRINT "H3  ";"MAX FLARE DIAMETER";H3
320   PRINT "  FLARE ANGLE"
330   BEEP
340   INPUT H4
350   PRINT "H4  ";"FLARE ANGLE";H4
460   PRINT "  CENTER OF GRAVITY OF PROJECTILE: "
470   BEEP
480   INPUT C2
491   PRINT "C2  ";"CENTER OF GRAVITY OF PROJECTILE";C2
492   PRINT
493   PRINT
500   PRINT "INPUT 1.0 CALIBER REFERENCE DIAMETER (INCHES): "
510   BEEP
520   INPUT D
521   PRINT "D  ";"INPUT 1.0 CALIBER REFERENCE DIAMETER (INCHES)";D
530   PRINT "INPUT 1.0 CALIBER REFERENCE DIAMETER (MILLIMETERS): "
540   BEEP
550   INPUT D1
551   PRINT "D1  ";"INPUT NORMALIZED PROJECTILE WEIGHT (MILLIMETERS):";D1
560   PRINT "INPUT NORMALIZED PROJECTILE WEIGHT (CUBIC CALIBERS): "
570   BEEP
580   INPUT W
581   PRINT "W  ";"INPUT NORMALIZED PROJECTILE WEIGHT (CUBIC CALIBERS):";W
590   PRINT "INPUT AXIAL MOMENT OF INERTIA (CALIBERS**5): "
600   BEEP
610   INPUT I
611   PRINT "I  ";"INPUT AXIAL MOMENT OF INERTIA (CALIBERS**5):";I
620   PRINT "INPUT TRANSVERSE MOMENT OF INERTIA (CALIBERS**5): "
630   BEEP
```

```
640    INPUT I1
641    PRINT "I1  ";"INPUT TRANSVERSE MOMENT OF INEPTIA (CALIBERS**5):";I1
650    PRINT
660    PRINT "INPUT MACH NUMBER AT MUZZLE: "
670    BEEP
680    INPUT M0
681    PRINT "M0  ";"INPUT MACH NUMBER AT MUZZLE:";M0
690    PRINT "INPUT MAXIMUM RANGE (METERS): "
700    BEEP
710    INPUT S
720    S9=S
730    PRINT PAGE
740    DEG
750    B=20
760    B1=25
780    B3=L+L1
790    H6=H3/2
800    H7=1/.5*(H3-1)
801    H8=B3+H7
840 Image_1:   IMAGE 2D.2D
850    Z=0
940    PLOTTER IS 13,"GRAPHICS"
950    Iplot=0
960 Graphics:  GRAPHICS
970    EXIT ALPHA
980    SCALE -6,40,5,28
990    X_scale_factor=42/23
1000   MOVE -1,20
1010   DRAW 20,20
1020   MOVE 0,B
1030   DRAW L,B+.5
1040   DRAW L,B-.5
1050   DRAW 0,B
1060   MOVE L,B+.5
1070   DRAW B3,B+.5
1080   DRAW B3,B-.5
1090   DRAW L,B-.5
1100   MOVE B3,B+.5
1110   DRAW H7+B3,B+H6
1120   DRAW H7+B3,B-H6
1130   DRAW B3,B-.5
1540   MOVE 0,B-.2
1550   DRAW 0,B-5
1560   MOVE L,B-.7
1570   DRAW L,B-2
1580   MOVE B3,B-.7
1610   DRAW B3,B-4
1640   MOVE -.25,B-1.5
1650   DRAW L+.25,B-1.5
1660   MOVE -4,B-1.5
1670   LORG 2
1680   LABEL L
1690   MOVE -.25,B-3
1700   DRAW B3+.25,B-3
1710   IPLOT -B3-4.8,0,-2
1720   LABEL B3
1730   MOVE -.25,B-3
1740   DRAW B3+.25,B-3
1750   MOVE -.25,B-4.5
1760   DRAW H8+.25,B-4.5
1770   IPLOT -H8-4.8,0,-2
1780   LABEL H8
1781   MOVE H8,B-H6-.2
1782   DRAW H8,B-5
1783   MOVE H9,B-4.5
1784   DRAW H8,B-4.5
```

```
1810  MOVE 0,B+.2
1820  DRAW 0,B+5
1830  MOVE C2,B+3
1840  DRAW C2,B+5
1850  MOVE -.25,B+4.5
1860  DRAW C2+.25,B+4.5
1870  IPLOT -C2-4.8,0,-2
1880  LABEL C2
1881  MOVE -.25,B+4.5
1882  DRAW C2,B+4.5
1890  MOVE -.25,2+B
1900  DRAW P1+P2,2+B
1901  IPLOT -P1-P2-4.8,0,-2
1910  LABEL P1
1920  MOVE P1+P2,2+B
1930  DRAW P1+P2+.2,2+B
1940  MOVE P1+P2+.3,2+B
1950  LABEL P2
1960  LORG 1
1970  REM
1980  REM
1990  MOVE C2-.1,B-.1
2000  DRAW C2+.1,B+.12
2010  MOVE C2+.1,B-.12
2020  DRAW C2-.1,B+.12
2030  MOVE P1,B+.7
2040  DRAW P1,B+2.5
2050  MOVE P1+P2,B+.7
2060  DRAW P1+P2,B+2.5
2070  MOVE C2,B
2080  LORG 5
2090  LABEL "O"
2110  MOVE P1,.5+B
2120  DRAW P1+P2,-.5+B
2130  DRAW P1+P2,.5+B
2140  DRAW P1,-.5+B
2150  DRAW P1,.5+B
2151  LORG 1
2160  MOVE H8+.25,B+.8
2170  REM
2180  REM
2190  LABEL H4;"DEG FLARE"
3080  LORG 1
3100  MOVE 1.5,B-9
3110  LABEL "WT ="
3120  MOVE 4.5,B-9
3130  LABEL W;" WCAL3"
3140  MOVE 1.5,B-10
3150  LABEL "IX ="
3160  MOVE 4.5,B-10
3170  LABEL I;" ICAL5"
3180  MOVE 1.5,B-11
3190  LABEL "IY ="
3200  MOVE 4.5,B-11
3210  LABEL I1;" ICAL5"
3220  MOVE 1.5,B-12
3230  LABEL "DIA="
3240  MOVE 4.5,B-12
3250  IF D=0 THEN LABEL D1;" MM/CAL"
3260  IF D<>0 THEN LABEL D;" IN/CAL"
3270  MOVE 8.25,26
3280  LABEL "LONG ROD FLARED PROJECTILE DESIGN"
3290  GSTORE Array_t(*)
3300  GSTORE Array_b(*),0,227
3310  EXIT GRAPHICS
3320  ALPHA
```

```
3330  IF Iplot=0 THEN Ask_it
3340  PLOTTER 7,5 IS OFF
3350  GCLEAR
3360  GOTO Print_input
3370 Ask_it: PRINT PAGE
3380  Iplot=1
3390  PRINT "DO YOU WANT A HARD COPY OF THE PLOT? (Y or N)"
3400  BEEP
3410  INPUT Reply$
3420  IF Reply$<>"Y" THEN Keep_picture
3430  PRINT "DO YOU WANT THE COPY ON THE PRINTER (0), OR ON THE PEN PLOTTER (1)?
"
3440  BEEP
3450  INPUT Plot_device
3460  IF Plot_device=0 THEN Dump_graphics
3470  PRINT "SET PEN PLOTTER AND PRESS CONTINUE WHEN READY"
3480  BEEP
3490  PAUSE
3500  PLOTTER IS 7,5,"9872A"
3510  GLOAD Array_t(*)
3520  GLOAD Array_b(*),0,227
3530  PLOTTER 13 IS OFF
3540  GOTO Graphics
3550 Keep_picture:  PRINT "PRESS CONTINUE TO RETURN PLOT. THE PLOT"
3560  PRINT "WILL REMAIN ON THE SCREEN UNTIL CONTINUE IS PRESSED AGAIN."
3570  BEEP
3580  PAUSE
3590  EXIT ALPHA
3600  GRAPHICS
3610  PAUSE
3620  GCLEAR
3630  EXIT GRAPHICS
3640  ALPHA
3650  GOTO Print_input
3660 Dump_graphics:  EXIT ALPHA
3670  GRAPHICS
3680  DUMP GRAPHICS
3690  GCLEAR
3700  EXIT GRAPHICS
3710 Print_input:  PRINT PAGE
3720  PRINT "DO YOU WANT THE INITIAL DATA PRINTED OUT? (Y or N)"
3730  BEEP
3740  INPUT Reply$
3750  IF Reply$<>"Y" THEN Menu
3760  PRINTER IS 0
3770  PRINT
3780  PRINT "ALL VALUES ARE IN CALIBERS UNLESS OTHERWISE NOTED"
3790  PRINT
3800  PRINT "CONICAL NOSE LENGTH: ";L
3810  PRINT "CYLINDRICAL BODY LENGTH: ";L1
3820  PRINT "GROOVE LOCATION/NOSE: ";P1
3830  PRINT "GROOVE LENGTH: ";P2
3840  PRINT "MAX FLARE DIAMETER:";H3
3850  PRINT "FLARE ANGLE: ";H4
3900  PRINT USING Image_1;F
3930  PRINT "CENTER OF GRAVITY: ";C2
3940  PRINT "MACH NUMBER AT MUZZLE: ";M0
3950  PRINT "MAXIMUM RANGE (METERS): ";S
3960  PRINT "PROJECTILE WEIGHT (CAL3): ";W
3970  PRINT "AXIAL MOMENT OF INERTIA (CAL5): ";I
3980  PRINT "TRANSVERSE MOMENT OF INERTIA (CAL5): ";I1
3990  IF D<>0 THEN PRINT "1.0 CALIBER REFERENCE DIAMETER (IN.): ";D
4000  IF D1<>0 THEN PRINT "1.0 CALIBER REFERENCE DIAMETER (MM): ";D1
4010  PRINT LIN(5)
4020  PRINTER IS 16
4030 Menu:  PRINT PAGE
```

```
4040 Menu_list: PRINT "OPTIONS:"
4050  PRINT "  0 - END PROGRAM"
4060  PRINT "  1 - NOMENCLATURE"
4070  PRINT "  2 - TABLE OF AERODYNAMIC COEFFICIENTS"
4080  PRINT "  3 - CNAT vs. MACH NUMBER PLOT"
4090  PRINT "  4 - CDT vs. MACH NUMBER PLOT"
4100  PRINT "  5 - VELOCITY vs. RANGE PLOT"
4110  PRINT "  6 - CMAT, CG vs. MACH NUMBER PLOT"
4120  PRINT "  7 - J ZETA vs. MACH NUMBER PLOT"
4130  PRINT "  8 - LONG ROD FLARED PROJECTILE DESIGN"
4140  PRINT "ENTER SELECTION:"
4150  BEEP
4160  INPUT Option
4170  IF Option=0 THEN End
4180  IF Computed<>0 THEN Where_to
4190  G1=W
4200  G2=I1
4210  G6=L+L1
4220  J2=L/SQR(L*L+.25)
4230  J3=.5*(H3-1)/TAN(H4)
4240  M=2
4250  FOR Y=1 TO 7
4260  G3=SQR(M*M-1)
4270  G4=G3/L
4280  G5=L1/G3
4290  Q1(Y)=M
4300  G7=(1.9+1.3*G4+.0149*G5)*(1/G3^.7)*(.6103+.036*G6)
4330  G8=TAN(F)/G3
4340  G9=(.89+.75*G4+.5*G5)*(1/G3^.53)*(G3/M)^2.5
4350  J1=G7*G9
4360  Q(1,Y)=G7
4370  Q(2,Y)=G9
4380  Q(3,Y)=J1
4390  J4=(-.67/H3+2.67)*COS(H4)*M/G3
4400  J5=L+L1+.1*(H3-1)/TAN(H4)
4410  J6=J4*J5
4491  J=J4+G7
4500  Q(4,Y)=J4
4510  K1=J
4520  K2=J1+J6
4530  K3=K2/J
4540  K4=C2-K3
4550  K5=K4*J
4560  K6=K5
4570  Q(5,Y)=J
4580  Q(6,Y)=K2
4590  Q(7,Y)=K4
4600  Q(8,Y)=K5
4610  J=6+J/10
4620  K5=6+K5*6/220
4630  K7=M*2-3.5
4640  K8=J
4650  K9=K7
4660  T1=K5
4670  T2=2*L/J2+4*L1+4*J3/COS(H4)*(1+J3*TAN(H4))
4700  T5=M^.28*L^1.73
4710  T5=.7/T5
4711  T6=EXP(.6*(H4/57.3))
4720  T6=(.265-.048*M)*H3^2*T6
4730  T7=T2*(.004974-.000721*M)
4731  T9=3*H4/57.3/M*(.75-.6/H3)
4780  F1=.00025*EXP(3.9*LOG(M))*P2
4790  F2=F1*(T5+T7+T9)
4800  F4=T5+T6+T7+T9+F2
4810  P4=F4
4820  REM
```

```
4830  REM
4840  Q(9,Y)=T5
4850  Q(10,Y)=T6
4860  Q(11,Y)=T7
4870  Q(12,Y)=F2
4890  Q(14,Y)=T9
4930  Q(18,Y)=F4
4940  IF M=3 THEN F6=F4
4950  F4=F4+5+6
4960  IF M=5 THEN F7=(F4-6)/5
4970  F8=M*2+4
4980  F9=K1-F5
4990  Q(19,Y)=F9
5000  N1=G2/G1*(F9/K6)
5010  Q(20,Y)=N1
5020  M=M+.5
5030  N1=6+N1/2
5040  N2=N1
5050  O2=F8
5060  O3=F4
5070  NEXT Y
5080  N5=500
5090  Y=1
5100  N3=(F7-F6)/2
5110  N4=F6-3*N3
5120  N6=PI*.075/62.4/8*N4/W
5130  N7=N3+N4/M0
5140 Skip_6: IF D>0 THEN N8=EXP(S*N6*39.37/D)
5150  IF D1>0 THEN N8=EXP(S*N6*1000/D1)
5160  N9=N4/(N7*N8-N3)
5170  N0=(M0-N9)*341380
5180  V(Y)=N9*341.38
5190  N0=N0/S
5200  R2(Y)=S
5210  R3(Y)=N0
5220  O4=N9
5230  O5=S
5240  S=S-N5
5250  Y=Y+1
5260  IF S<>0 THEN Skip_6
5270  N3=(F7-F6)/2
5280  Y1=Y
5290  R2(Y)=0
5300  R3(Y)=R3(Y-1)
5310  V(Y)=M0*341.38
5320  N4=F6-3*N3
5330  N6=PI*.075/62.4/8*N4/W
5340  N7=N3+N4/M0
5350  IF D>0 THEN N8=EXP(O5*N6*39.37/D)      !************-- (1000?)
5360  IF D1>0 THEN N8=EXP(O5*N6*1000/D1)
5370  N9=N4/(N7*N8-N3)
5380  N0=(M0-N9)*341380
5390  N0=N0/O5
5400  O6=I1/K6*8*PI/.0012
5410  O6=SQR(ABS(O6))
5420  IF D>0 THEN O1=O6*D/39.37
5430  IF D1>0 THEN O1=O6*D1/1000
5440  Computed=1
5450 Where_to: ON Option GOTO Nomenclature,Coef_table,S_plot,S_plot,S_plot,S_plo
t,S_plot,Proj_design
5460 S_plot:  PRINT PAGE
5470  PRINT "DO YOU WANT THE PLOT ON THE SCREEN (0), OR ON THE"
5480  PRINT "  PEN PLOTTER (1)?"
5490  BEEP
5500  INPUT Plot_device
5510  IF (Plot_device<>0) AND (Plot_device<>1) THEN Plot_device=0
```

```
5520  IF Plot_device=0 THEN Skip_reset
5530  PRINT "RESET PLOTTER PEN LIMITS AND PRESS CONTINUE WHEN READY"
5540  BEEP
5550  PAUSE
5560  PLOTTER IS 7,5,"9872A"
5570  GOTO Do_plot
5580 Skip_reset:  PLOTTER IS 13,"GRAPHICS"
5590 Do_plot: GRAPHICS
5600  EXIT ALPHA
5610  ON Option GOTO Nomenclature,Coef_table,Cnat,Cdt,Vel_range,Cmat,J_zeta,Proj
_design
5620 E_plot:  IF Plot_device=0 THEN End_screen
5630  GCLEAR
5640  PEN 0
5650  EXIT GRAPHICS
5660  PLOTTER 7,5 IS OFF
5670  ALPHA
5680  GOTO Menu
5690 End_screen:  EXIT GRAPHICS
5700  ALPHA
5710  PRINT "DO YOU WANT A COPY OF THE PLOT ON THE PRINTER? (Y or N)"
5720  BEEP
5730  INPUT Copy$
5740  IF Copy$="Y" THEN DUMP GRAPHICS
5750  PRINT "PRESS CONTINUE TO RETURN PLOT. THE PLOT WILL REMAIN"
5760  PRINT "  ON THE SCREEN UNTIL CONTINUE IS PRESSED AGAIN."
5770  BEEP
5780  PAUSE
5790  EXIT ALPHA
5800  GRAPHICS
5810  PAUSE
5820  GCLEAR
5830  EXIT GRAPHICS
5840  PLOTTER 13 IS OFF
5850  ALPHA
5860  GOTO Menu
5870 End:  PRINT PAGE
5880  END
5890 Nomenclature:  PRINT PAGE
5900  PRINT "DO YOU WANT THE PRINTOUT ON THE SCREEN (0), OR ON THE PRINTER (1)?"
5910  BEEP
5920  INPUT Printer
5930  IF Printer=0 THEN Do_it
5940  PRINTER IS 0
5950  PRINT LIN(2)
5960 Do_it: PRINT "                              NOMENCLATURE"
5970  PRINT
5980  PRINT "CNAB     Slope of the Normal Force Coefficient for the projectile bo
dy"
5990  PRINT "XCPB     Pressure coefficient for the projectile body"
6000  PRINT "CMAB     Slope of the Pitching Moment Coefficient for the projectile
 body"
6010  PRINT "CNAF     Slope OF THE Normal Force Coefficient for the projectile fl
are"
6020  PRINT "CNAT     Slope of the Total Normal Force Coefficient"
6030  PRINT "CMAT     Slope of the Total Pitching Moment Coefficient"
6040  PRINT "CMAT,CG Slope of the Total Pitching Moment Coefficient about the"
6050  PRINT "         center of gravity"
6060  PRINT "CDWN     Coefficient of wave drag for the projectile nose"
6070  PRINT "CDB      Base drag coefficient for the projectile"
6080  PRINT "CDV      Viscous drag coefficient for the projectile"
6090  PRINT "CDGR     Profile drag of grooved section of body"
6110  PRINT "CDWF     Wave drag coefficient for the projectile flare"
6150  PRINT "CDT      Total drag coefficient"
6160  PRINT "CLA      Slope of the lift coefficient"
6170  PRINT "J ZETA  Aerodynamic jump factor"
```

```
6180  IF Printer=0 THEN Beep
6190  PRINT LIN(5)
6200  PRINTER IS 16
6210 Beep: BEEP
6220  PRINT LIN(1);"PRESS CONTINUE WHEN READY TO RETURN TO MENU"
6230  PAUSE
6240  GOTO Menu
6250 Coef_table:  PRINT PAGE
6260  PRINT "DO YOU WANT THE TABLE ON THE SCREEN (0), OR ON THE PRINTER (1)?"
6270  BEEP
6280  INPUT Printer
6290  PRINT PAGE
6300  IF Printer<>0 THEN PRINTER IS 0
6310  PRINT "                        STATIC AERODYNAMIC COEFFICIENTS FOR"
6320  PRINT "                            LONG ROD FLAPED PROJECTILES"
6330  PRINT
6340  PRINT USING Image_2;"MACH NUMBER"
6350 Image_2: IMAGE 30X,11A
6360  PRINT
6370  PRINT USING Image_3;"2.0","2.5","3.0","3.5","4.0","4.5","5.0"
6380 Image_3: IMAGE 12X,3A,6X,3A,7X,3A,7X,4(3A,6X)
6390 Image_4: IMAGE 7A,2(1X,4D.3D),2(2X,4D.3D),3(1X,4D.3D)
6400  PRINT USING Image_4;"CNAB   ",Q(1,1),Q(1,2),Q(1,3),Q(1,4),Q(1,5),Q(1,6),Q(
1,7)
6410  PRINT USING Image_4;"XCPB   ",Q(2,1),Q(2,2),Q(2,3),Q(2,4),Q(2,5),Q(2,6),Q(
2,7)
6420  PRINT USING Image_4;"CMAB   ",Q(3,1),Q(3,2),Q(3,3),Q(3,4),Q(3,5),Q(3,6),Q(
3,7)
6430  PRINT USING Image_4;"CNAF   ",Q(4,1),Q(4,2),Q(4,3),Q(4,4),Q(4,5),Q(4,6),Q(
4,7)
6440  PRINT USING Image_4;"CNAT   ",Q(5,1),Q(5,2),Q(5,3),Q(5,4),Q(5,5),Q(5,6),Q(
5,7)
6450  PRINT USING Image_4;"CMAT   ",Q(6,1),Q(6,2),Q(6,3),Q(6,4),Q(6,5),Q(6,6),Q(
6,7)
6460  PRINT USING Image_4;"CG-CP  ",Q(7,1),Q(7,2),Q(7,3),Q(7,4),Q(7,5),Q(7,6),Q(
7,7)
6470  PRINT USING Image_4;"CMAT,CG",Q(8,1),Q(8,2),Q(8,3),Q(8,4),Q(8,5),Q(8,6),Q(
8,7)
6480  PRINT USING Image_4;"CDWN   ",Q(9,1),Q(9,2),Q(9,3),Q(9,4),Q(9,5),Q(9,6),Q(
9,7)
6490  PRINT USING Image_4;"CDB    ",Q(10,1),Q(10,2),Q(10,3),Q(10,4),Q(10,5),Q(10
,6),Q(10,7)
6500  PRINT USING Image_4;"CDV    ",Q(11,1),Q(11,2),Q(11,3),Q(11,4),Q(11,5),Q(11
,6),Q(11,7)
6510  PRINT USING Image_4;"CDGR   ",Q(12,1),Q(12,2),Q(12,3),Q(12,4),Q(12,5),Q(12
,6),Q(12,7)
6530  PRINT USING Image_4;"CDWF   ",Q(14,1),Q(14,2),Q(14,3),Q(14,4),Q(14,5),Q(14
,6),Q(14,7)
6570  PRINT USING Image_4;"CDT    ",Q(18,1),Q(18,2),Q(18,3),Q(18,4),Q(18,5),Q(18
,6),Q(18,7)
6580  PRINT USING Image_4;"CLA    ",Q(19,1),Q(19,2),Q(19,3),Q(19,4),Q(19,5),Q(19
,6),Q(19,7)
6590  PRINT USING Image_4;"J ZETA ",Q(20,1),Q(20,2),Q(20,3),Q(20,4),Q(20,5),Q(20
,6),Q(20,7)
6600  IF Printer=0 THEN Skip_7
6610  PRINT LIN(5)
6620  PRINTER IS 16
6630  GOTO Menu
6640 Skip_7:  BEEP
6650  PRINT LIN(1);"PRESS CONTINUE WHEN READY TO RETURN TO MENU"
6660  PAUSE
6670  GOTO Menu
6680 Cnat: SCALE 1.4,5.2,-6,31
6690  CLIP 2,5,0,30
6700  LAXES .25,2,2,0,-4,3
6710  UNCLIP
```

```
6720  LDIR 0
6730  LORG 5
6740  MOVE 3.5,-3
6750  LABEL "MACH NUMBER"
6760  LDIR 90
6770  MOVE 1.7,15
6780  LABEL "CNAT"
6790  MOVE Q1(1),Q(5,1)
6800  FOR I=2 TO 7
6810  DRAW Q1(I),Q(5,I)
6820  NEXT I
6830  GOTO E_plot
6840 Cdt: SCALE 1.4,5.2,-.2,1.05
6850  CLIP 2,5,0,1
6860  LAXES .25,.1,2,0,-4,2
6870  UNCLIP
6880  LDIR 0
6890  LORG 5
6900  MOVE 3.5,-.1
6910  LABEL "MACH NUMBER"
6920  LDIR 90
6930  MOVE 1.7,.5
6940  LABEL "CDT"
6950  MOVE Q1(1),Q(10,1)
6960  FOR I=2 TO 7
6970  DRAW Q1(I),Q(10,I)
6980  NEXT I
6990  GOTO E_plot
7000 Vel_range: SCALE -S9/5000,31*S9/30000,-1600,2400
7010  CLIP 0,S9/1000,0,2000
7020  LAXES .5,250,0,0,-1,1
7030  UNCLIP
7040  LDIR 0
7050  LORG 5
7060  MOVE S9/2000,-250
7070  LABEL "RANGE (KM)"
7080  LDIR 90
7090  MOVE -S9/8000,1000
7100  LABEL "VEL (M/S)"
7110  MOVE R2(1)/1000,V(1)
7120  FOR I=2 TO Y1
7130  DRAW R2(I)/1000,V(I)
7140  NEXT I
7150  LDIR 0
7160  LORG 1
7170  MOVE 0,2150
7180 Image_5:  IMAGE "MUZZLE MACH No.",2D.3D,", INITIAL YAW CYCLE",4D.3D,"M"
7190  LABEL USING Image_5;M0,O1
7200  MOVE 0,-500
7210 Image_6: IMAGE "RANGE",5D," M, RETARDATION",4D.3D," M/S/KM"
7220  FOR I=Y1 TO 1 STEP -1
7230  LABEL USING Image_6;R2(I),R3(I)
7240  IPLOT 0,-30,-2
7250  NEXT I
7260  GOTO E_plot
7270 Cmat: SCALE 1.4,5.2,10,-23
7280  CLIP 2,5,6,-22
7290  LAXES .25,2,2,0,-4,2
7300  UNCLIP
7310  LDIR 0
7320  LORG 5
7330  MOVE 3.5,5
7340  LABEL "MACH NUMBER"
7350  LDIR 90
7360  MOVE 1.55,-8
7370  LABEL "CMAT,CG"
```

```
7460  MOVE Q1(1),Q(8,1)
7470  FOR I=2 TO 7
7480  DRAW Q1(I),Q(8,I)
7490  NEXT I
7500  GOTO E_plot
7510 J_zeta: SCALE 1.4,5.2,-2,20.5
7520  CLIP 2,5,0,20
7530  LAXES .25,1,2,0,-4,2
7540  UNCLIP
7550  LDIR 0
7560  LORG 5
7570  MOVE 3.5,-1
7580  LABEL "MACH NUMBER"
7590  LDIR 90
7600  MOVE 1.6,10
7610  LABEL "J ZETA"
7620  X_inc=1.8
7630  LDIR 0
7640  LORG 2
7650  FOR I=2 TO 20 STEP 2
7660  MOVE X_inc,I
7670  LABEL "-"
7680  IF I>7 THEN X_inc=1.75
7690  NEXT I
7700  MOVE Q1(1),ABS(Q(20,1))
7710  FOR I=2 TO 7
7720  DRAW Q1(I),ABS(Q(20,I))
7730  NEXT I
7740  GOTO E_plot
```

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